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The effect of fire on collembolan populations of Mata da Margaraça (Portugal)

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Abstract

A monthly sampling programme was carried out in 1989-1990 in order to analyse the effects of severe fire on edaphic populations of Collembola in the protected area of Mata da Margaraça. Three sampling stations were established in the most intensely burned area, taking into account the dominant plant species: *Quercus robur, Castanea sativa* and *Viburnum tinus*. Three other corresponding stations with the same plant species were selected in the unburned area, for comparative purposes. Biotope description was achieved through chemical and physical analysis of the litter and soil upper layer. Flucuations of abiotic nature were observed, namely in the temperature, water content and pH levels of the burned sites. These alterations are primarily associated to the absence of a litter layer with the corresponding loss of thermostable properties and moisture holding capacity. The study of the collembolan communities structure, by means of agglomerative cluster analysis and the application of a similarity coefficient among sampling stations, puts in evidence approximate values of specific richness for all populations, with the burned sites presenting higher densities and a slight decrease in the number of species. Certain species of Collembola associated either to burned or unburned stations were also identified, as well as the exclusivity of a few species to a certain site.

Keywords: Collembola, edaphic populations, wildfire.

L'effet du feu sur les populations de Collemboles de Mata da Margaraça (Portugal).

Résumé

Un programme d'échantillonnage mensuel a été mené en 1989/1990 pour analyser les effets de feux sévères sur les populations édaphiques de Collemboles dans la zone protégée de Mata da Margaraça. Trois sites d'échantillonnage ont été établis dans la zone la plus fortement brûlée, tenant compte des espèces ligneuses dominantes : *Quercus robur, Castanea sativa* et *Viburnum tinus*. Trois autres stations correspondant aux mêmes espèces ont été choisies dans la zone non brûlée, à des fins comparatives. La caractérisation des biotopes a été réalisée par des analyses physico-chimiques de la litière et de l'horizon supérieur du sol. Les fluctuations des facteurs abiotiques ont été relevées, notamment pour la température, l'humidité et le pH des sites brûlés. Ces altérations sont principalement associées à l'absence de litière, liée à la perte des propriétés de tampon thermique et de la capacité de rétention hydrique. L'étude de la structure des peuplements de Collemboles, par l'analyse des agglomérations de clusters et par l'application d'un coefficient de similarité entre stations, met en évidence des valeurs voisines de richesse spécifique pour toutes les communautés, les sites brûlés présentant des densités plus élevées et une légère diminution du nombre d'espèces. Certaines espèces de Collemboles associées soit aux sites brûlés, soit aux sites non brûlés, ont également été identifiées, de même que la présence exclusive de quelques espèces dans un site précis.

Mots-clés : Collembola, populations édaphiques, feu.

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1. INTRODUCTION

Fire is a major factor structuring animal and plant communities in most mediterranean ecosystems and is generally considered to have a deleterious effect upon forest soils, namely in the organic matter content and in mesofauna densities. The destruction of litter habitats, desiccation of upper soil layers and reduction of epigeal invertebrate populations cause drastic changes in food supplies, water content, temperature and pH levels, that induce modifications in the microclimatic, microhabitat and trophic conditions suitable to soil organisms (Cancela da Fonseca and Betsch, 1990).

Collembola constitute the second most abundant *taxon* of soil arthropods. They occur densely distributed in moist soils what is specially true in woodland humus. Following the rupture of biocenotical balance caused by fire, a reduction on its populations is immediate. However, DiCastri and Vitali-DiCastri (1981) report that Collembola react quickly to environmental changes: an initial decrease is followed by an increase to higher than preburn levels at the third year. Collembola are important indicators of soil conditions and contribute to nutrient cycling as they are active in the breakdown of organic tissue, which promotes bacterial and fungal decomposition. It is, therefore, considered important to evaluate the effects of fire on collembolan populations.

2. MATERIAL AND METHODS

The study area is located within the Paisagem Protegida da Serra do Açor, Arganil, 75 km west of Coimbra, on the southwestern counterforts of Serra da Estrela at an elevation of 440-740 meters over sea level. It occupies a total surface of 50 ha and is subjected to an oceanic climate of mild temperatures and abundant rainfall, with a certain amount of summer drought which gives it a mediterranean profile. The topography is characterized by steady slopes of 25-30% and it is covered mainly by deciduous trees of autochthonous atlantic character.

In September 1987, the study area was swept by a high intensity wildfire propagated by gusty winds which consumed approximately 80% of Mata da Margaraça. Plant regenerations was well under way at the beginning of the experiment in February 1989, but a mosaic pattern created by different levels of fire intensity was still noticeable.

The study sites were selected taking into account the most significant plant species. They were: *Quercus robur* L. (common oak) –station 1– unburned; station 4– burned. *Castanea sativa* Miller (chestnut) –station 2– unburned; station 5 –burned. *Viburnum tinus* L. (laurestinus) –station 3– unburned; station 6 –burned.

Two soil samples of 500 cm^3, covering a surface area of 100 cm^2 and reaching a depth of 5 cm, were randomly obtained with a seasonal frequency in April, July, November 1989 and January 1990 in each station for analysis of collembolan populations. Every month, from February 1989 to January 1990, samples of 1 000 cm^3 were collected in each sampling station for chemical analysis. The evaluated edaphic parameters were: temperature at the surface and at 5 cm depth; water content of the samples by drying at 105°C for 24 hours; pH, in distilled water, in 1N KCl and in 0.1 KCl (Dewis & Freitas, 1984).

Soil microarthropods were extracted using the Berlese-Tullgren funnel~~s~~ method, with a subsequent separation of the Collembola and identification at species level.

The analysis of the species distribution according to station's nature was done by using the Parametric Correlation Coefficient (Pearson's r) (R mode analysis) and the UPGMA as clustering method (Sneath & Sokal, 1973). Data treatment was performed with the NTSYS-pc 1.60 software system (Rohlf, 1990). To analyse the structural similarity of the communities in the different stations, the coefficient of Czekanowski was calculated for each seasonal sampling (Legendre & Legendre, 1979) using a "Basic Apple Soft" program, which was performed in a Apple II C microcomputer.

3. RESULTS

3.1. Abiotic parameters

As expected, thermic amplitudes were higher in the burned sites, both at the soil surface and at a depth of 5 cm (*fig.* 1-A and B). These differences are more evident during the summer season, with soil temperatures reaching 48°C in the surface of burned stations and 32°C at a depth of 5 cm, in July. Soil temperatures in unburned stations remained respectively 18°C and 12°C lower in the same period. The average annual soil water content values also display fluctuations expected in stations charred by fire (*fig.* 1-C). The presence of moisture in the soil occurs, most of the year, in all sampling stations, with a significant decrease during the summer period. Burned sites present higher water content levels than the unburned ones in Autumn and Winter and lower levels in Spring and Summer. The pH values show an unexpected increase in the acidity of the burned soil (*fig.* 2). In this study, variations between pH 3.9 and pH 5 were found for unburned soil samples, while values of pH 3.4 to pH 4.8 were obtained in the burned sites.

3.2. Population structure

The total number of collected Collembola reflected abundance differences between the burned and the

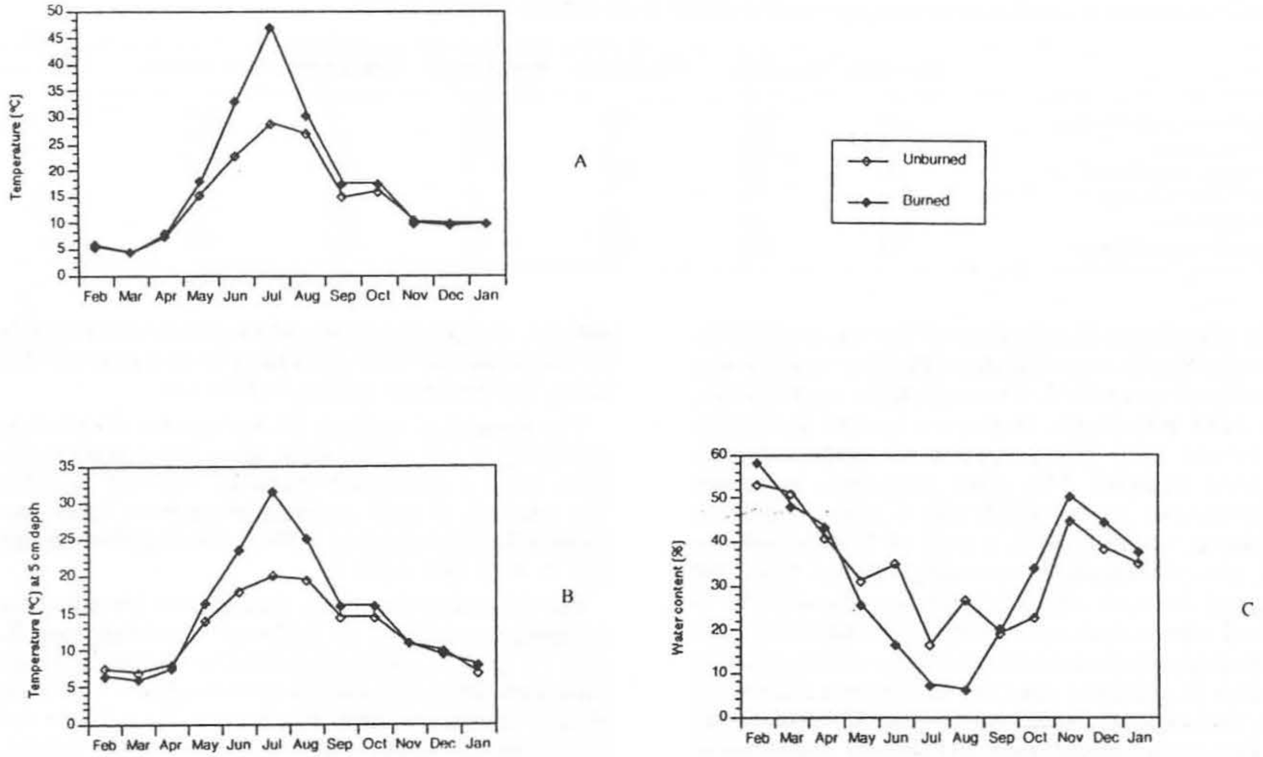

Figure 1. – Mean monthly values (February 1989-January 1990) for : A – surface temperatures; B – temperatures at 5 cm depth; C – water content.

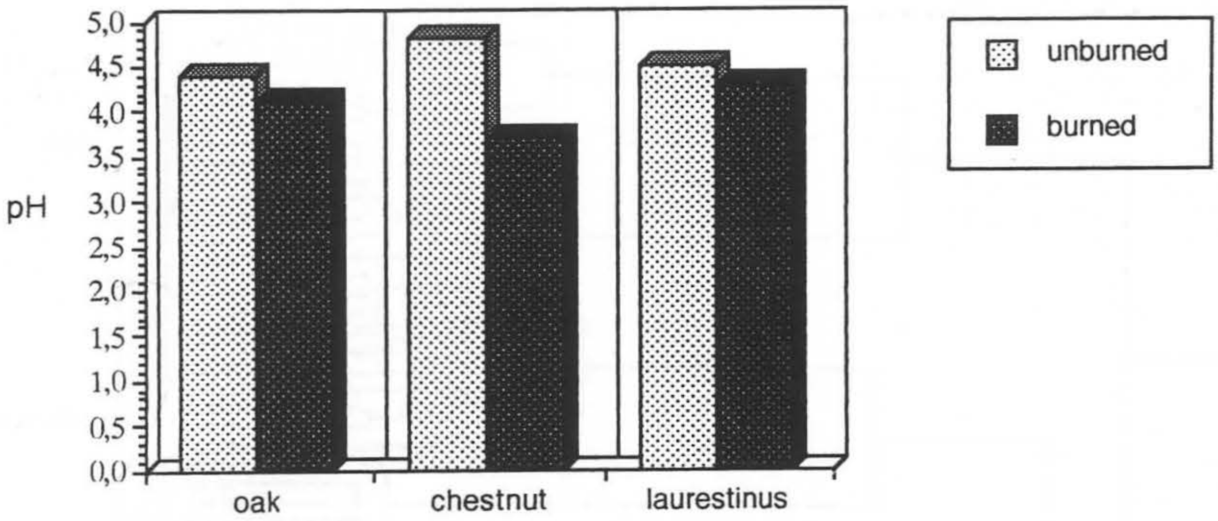

Figure 2. – Annual pH levels (February 1989-January 1990) for: A – the 6 sampling stations; B – the chestnut station (*Castanea sativa*).

unburned sites. 3 123 individuals were obtained in the unburned stations, compared to 3 701 in the burned ones. The seasonal samples of April (Spring), November (Autumn) and January (Winter) were analysed and 44 species of Collembola were identified among a total of 6 810 specimens found in the 6 sampling stations. No specimens were obtained in the samples of July. 2 726 specimens, representing 40% of the total and distributed by 38 species, were obtained in the Winter samples. In Spring were identified 41 species among 2 402 specimens (35.2%). The lowest density was found in the Autumn samples, where 1 682 (24,7%) specimens were identified as belonging to 32 species.

Table 1. – Abundance distribution of the most representative species in the different sampling stations.

	Unb. Oak	Burn. Oak	Unb. Chestn.	Burn. Chestn.	Unb. Laurest.	Burn. Laurest.	Total
Ceratophysella engadinensis	144	506	21	311	8	199	1 189
Onychiurus gisini	24	234	0	123	84	374	839
Tullbergia gr. *krausbaueri*	34	17	142	7	233	16	439
Folsomia quadrioculata	633	17	7	0	1	54	712
Isotomiella minor	192	18	81	2	100	8	401
Cryptopygus scapelliferus	44	212	354	31	111	555	1 307

The abundance distribution of the most representative species in the different sampling stations can be analysed on *table* 1. *Ceratophysella engadinensis*, with 1 189 individuals, displays a marked preference for burned sites (1 016 specimens against 173 in unburned stations). The same preference is visible in *Onychiurus gisini*, which has a lower degree of abundance, occuring with a total of 839 individuals. This species remained constantly absent from the unburned chestnut site. *Cryptopygus scapelliferus* is the best represented *taxon* with 1 307 individuals. Its distribution reflects a mixed tendency, reaching higher densities in unburned chestnut and burned laurestinus sites. *Tullbergia* gr. *krausbaueri* with 439 individuals and *Isotomiella minor* with 401 display approximate abundance levels and a similar preference for unburned stations. *Folsomia quadrioculata* reveals high affinity for unburned oak (633 specimens from a total of 712) being the dominant species in this site.

The numerical analysis of the species distribution according to site nature only takes into consideration links with a correlation equal or superior to 0.50. The analysis of each seasonal phenogram takes into account the data obtained in the remaining phenograms (*fig*. 3, 4, 5 and *table* 2).

The following taxonomic groups were identified for the Spring period (*fig*. 3): subgroup A and subgroup B, with 13 species better represented in burned oak and burned chestnut, constitute a specific cluster with high affinity for burned sites. *Brachystomella parvula* and *Proisotoma gisini* occur exclusively in burned stations. The 16 species with a marked preference for unburned

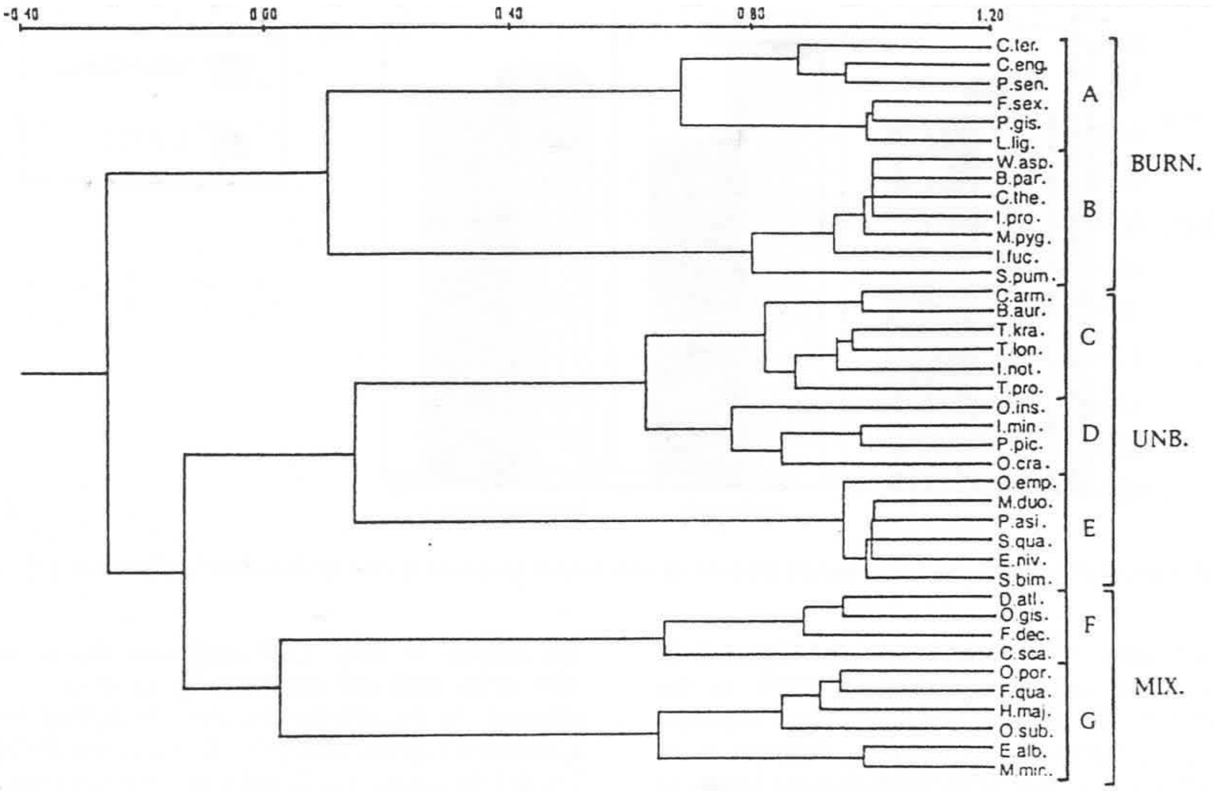

Figure 3. – Statistical analysis of the Spring species distribution according to biotope nature (R analysis). Cophenetic correlation = 0.8237. Groups and subgroups discussed in the text are indicated.

Table 2. – Seasonal distribution of the 44 collembolan species represented in the burned and unburned biotopes.

		Unburned oak			Burned oak			Unburned chestnut			Burned chestnut			Unburned laurestinus			Burned laurestinus		
Species	Abrev.	Spr.	Aut.	Win.	Spr.	Aut.	Win.	Spr.	Aut.	Win.	Spr.	Aut.	Win.	Spr.	Aut.	Win.	Spr.	Aut.	Win.
Ceratophysella tergilobata Cassagnau, 1954	C. ter.	1		41	17		3	4	1	3	27	1	2	11	3	20	4	1	7
Ceratophysella engadinensis Gisin, 1949	C. eng.	6	26	112	284	44	178	18	1	2	231	56	24	4	1	3	10	20	169
Ceratophysella armata (Nicolet, 1841)	C. arm.	8			2			8		38				8		30			4
Willemia aspinata Stach, 1949	W. asp.				6														
Odontella empodialis Stach, 1934	O. emp.	1						3		5			7			1			2
Microgastrura duodecimoculata Stach, 1922	M. duo.					45	7	9		2						1			5
Brachystomella parvula (Schäffer, 1896)	B. par.				4													14	73
Pseudachorutella asigillata (Börner, 1901)	P. asi.							2											
Micranurida pygmaea Börner, 1901	M. pyg.	2			12							6							
Bilobella aurantiaca (Caroli, 1912)	B. aur.	1						1	1					1	1				
Deutonura atlantica Deharveng, 1982	D. atl.										1				1		2	9	
Onychiurus insubrarius Gisin, 1952	O. ins.													11		18			
Onychiurus gisini Haybach, 1960	O. gis.	23	1		28	136	70				46	64	13	10	26	48	95	91	188
Onychiurus portucalensis Gama, 1964	O. por.	7															2		
Onychiurus subgranulosus Gama, 1964	O. sub.	4	10		2										11				
Tullbergia gr. *krausbaueri* (Börner, 1901)	T. kra.	10	3	21		13	4	20	59	63		7		39	49	135	1	12	3
Stenaphorura quadrispina Börner, 1901	S. qua.							46	37						6				
Uzelia kuehnelti Cassagnau, 1954	U. kue.						3												
Tetracanthella proxima Steiner, 1955	T. pro.							1		3				1					
Folsomia decemoculata Stach, 1946	F. dec.			1													180		23
Folsomia sexoculata (Tullberg, 1871)	F. sex.								31		43		29						
Folsomia quadrioculata (Tullberg, 1871)	F. qua.	114	166	353	17			1		6					1		2	30	22
Isotomodes productus (Axelson, 1906)	I. pro.	1			55							4							
Isotomiella minor (Schäffer, 1896)	I. min.	67	8	117	17		1	14	41	26	1	1		82		18	5		3
Proisotoma gisini Gama, 1964	P. gis.					18	41				4	13	46						1
Cryptopygus scapelliferus (Gisin, 1955)	C. sca.	44			10	68	134	135	59	160	14	10	7	47	7	57	211	150	194
Cryptopygus thermophilus (Axelson, 1900)	C. the.				28														
Pseudisotoma sensibilis (Tullberg, 1876)	P. sen.	1			34		3				44		3						1
Isotoma notabilis Schäffer, 1896	I. not.	16	12	10				32	17	9				36		46	3	1	2
Isotomurus palustris (Müller, 1776)	I. pal.						2						3						
Isotomurus fucicola (Reuter, 1891)	I. fuc.		14	2	3	3	10	1	93	7		5	27		20	2		30	5
Entomobrya albocincta (Templeton, 1835)	E. alb.	1											2				1		
Entomobrya nivalis (Lineu, 1758)	E. niv.				1			11											
Lepidocyrtus lignorum Fabricius, 1775	L. lig.		1	1			1				7	1					1	2	
Heteromurus major (Moniez, 1889)	H. maj.	19	13	5	1			5	1		1	1		5		7	1	1	1
Pseudosinella picta Börner, 1903	P. pic.	2	1	1		2			6					3					1
Tomocerus longicornis (Müller, 1776)	T. lon.	1						1						2					
Oncopodura crassicornis Shoebotham, 1911	O. cra.	4			4	10		1	4	2		1		7	1	3	2	3	
Megalothorax minimus Willem, 1990	M. min.	6	10	8		2	1	1	4						1	1	5	6	4
Sphaeridia pumilis (Krausbauer, 1898)	S. pum.	2			3														
Sminthurinus bimaculatus (Axelson, 1902)	S. bim.	1		2			1	7	2			1				1			3
Sminthurinus aureus (Lubbock, 1862)	S. aur.																	6	
Lipothrix lubbocki (Tullberg, 1872)	L. lub.		8						7	2					3				
Caprainea bremondi (Delamare et Bassot, 1957)	C. bre.		4			1													

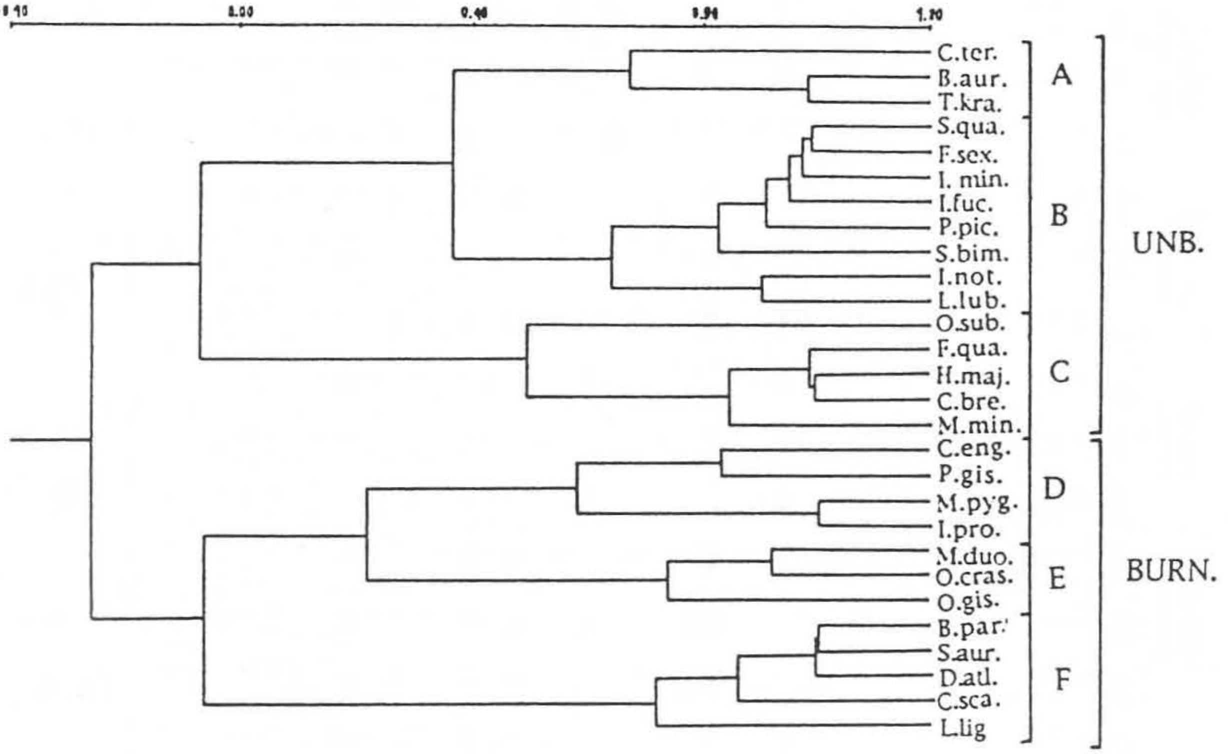

Figure 4. – Statistical analysis of the Autumn species distribution according to biotope nature (R analysis). Cophenetic correlation = 0.83592.

sites are clustered into 3 subgroups (C, D, E). There, 4 species display an exclusive character: *Bilobella aurantiaca, Stenaphorura quadrispina* and *Tetracanthella proxima* occur only in unburned sites, *Onychiurus insubrarius* is exclusive of the unburned laurestinus station. Subgroups F and G include 10 species, 8 of them occuring with variable densities in both burned and unburned sites, but showing a clear gradient of affinity to unburned ones. The analysis of similarity (Czekanowski's coefficient) among the 6 sampling stations in Spring (*fig.* 6-A) brings into evidence the intermediate characteristics of burned laurestinus. The high density of *Cryptopygus scapelliferus, Folsomia decemoculata* and *Onychiurus gisini* in this station is the responsible factor.

The same analysis performed on the Autumn data revealed a clear separation in the species associated either to burned or unburned stations (*fig.* 4). Three subgroups present a tendency for unburned sites: subgroups A and B, made up of 11 species found mostly in the unburned chestnut and unburned laurestinus stations and subgroup C with 5 species better represented in the unburned oak site but displaying a gradual decrease of specificity. Three species, *Bilobella aurantiaca, Stenaphorura quadrispina* and *Lipothrix lubbocki*, occur exclusively in unburned stations. The remaining 12 species are clustered into 3 subgroups with affinity for burned sites. The species in subgroups D and E occur with greater abundance in the burned chestnut and burned oak stations. Subgroup F includes the species more densely represented in the burned laurestinus site. *Brachystomella parvula* and *Proisotoma gisini* only appear in burned stations. In Autumn, the application of the Czekanowski's coefficient revealed high levels of similarity in the burned stations, specially between burned oak and burned chestnut (*fig.* 6-B). The lower degree of similarity found between unburned oak and the remaining stations may be due to the great abundance of *Folsomia quadrioculata*, constituting 55.7% of the specimens obtained in unburned oak, which produces a marked unevenness in the relative proportions of the species.

In Winter (*fig.* 5) 14 species were identified in unburned sites and 15 species in the burned ones, with clear gradients of distribution revealed inside the clusters. 4 subgroups are constituted by species with preference for unburned sites: subgroup A and subgroup B include the species better represented in unburned oak, in subgroup E are present species with preference for unburned chestnut and in subgroup F are the species with affinity for unburned laurestinus sites. *Onychiurus insubrarius* occurs in unburned laurestinus and *Tetracanthella proxima* and *Lipothrix lubbocki* in unburned stations both with character of exclusivity. The species in subgroup C display a mixed tendency concerning biotope nature, although the preferences for burned sites remain high. Subgroup D includes the

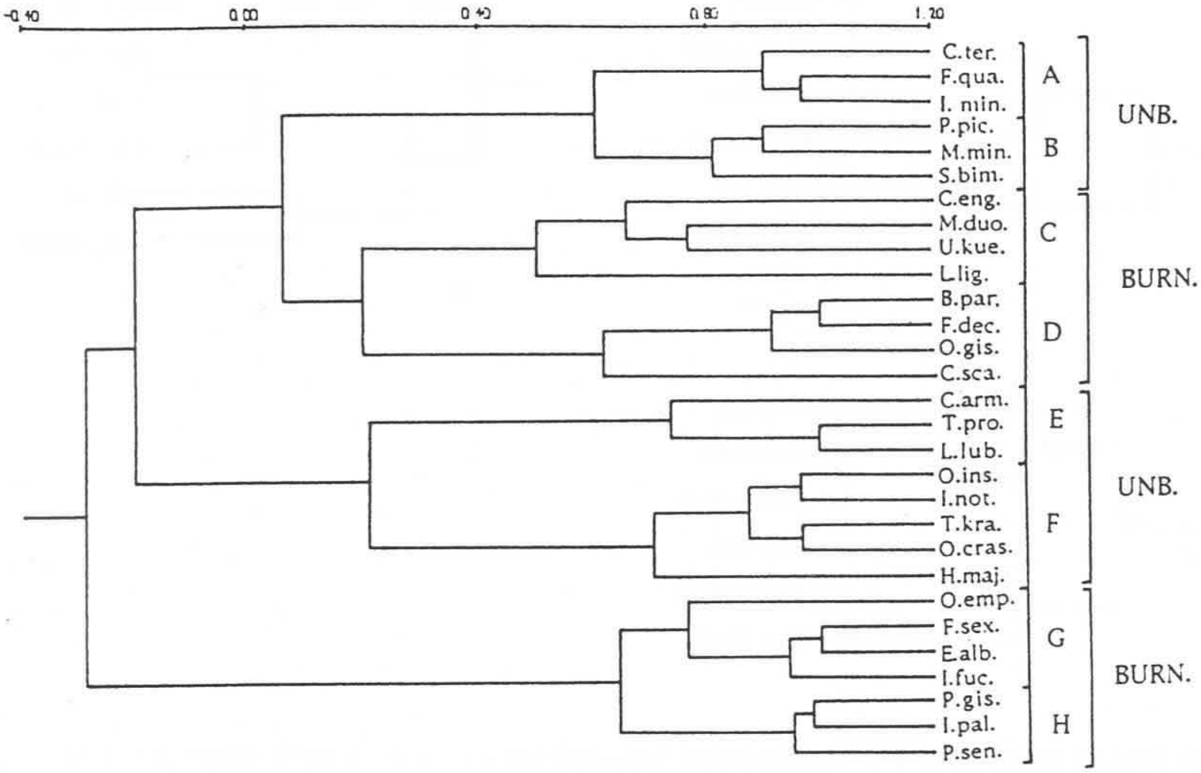

Figure 5. – Statistical analysis of the Winter species distribution according to biotope nature (R analysis). Cophenetic correlation = 0.80007.

species more densely represented in burned laurestinus and in subgroups G and H occur the species with preference for burned oak and burned chestnut sites. Once again, *Brachystomella parvula* and *Proisotoma gisini* appear only represented in burned stations. The phenogram that allows the analysis of similarity in Winter among the different sampling stations clearly reveals a separation between burned and unburned sites (*fig.* 6-C). The low similarity between unburned oak and the remaining unburned stations can, again, be explained by the high density of *Folsomia quadrioculata* in this site (52.3%), while the same pattern observed in burned chestnut relatively to the other burned stations may be due to lower total abundances occurring in this sampling station.

4. DISCUSSION

The fire in Mata da Margaraça caused some environmental changes, which weren't completely overcome 2 years after the perturbation. It is still possible to observe fluctuations of abiotic nature, namely in temperature and water content levels of the burned sampling stations.

The higher thermic amplitudes observed in the soil of burned sites are due to suppression by fire of forest floor vegetation with loss of the litter's protective effect, increased soil insolation related to the absence of shade provided by a full tree canopy cover and blackening of burned surfaces, which can effectively increase solar radiation absorption.

It is, however, hard to define temperature as a factor of direct influence on collembolan distribution if it isn't jointly considered with moisture. In forest soils, moisture conditions depend largely on the humus layer. During the humid season, the litter is able to imbibe large amounts of water, so that only heavy rains reach subjacent layers and tree roots; in dry periods, the litter layer effectively hinders evaporation from the soil. Both water-holding capacity and the ability to prevent evaporation are much reduced in burned sites. In addition, the higher temperature of a burned site tends to increase evaporation (Ahlgren, 1974).

The significant acidity of the burned stations when compared to unburned ones can hardly be assessed to fire. This tendency is better observed in the annual values obtained for chestnut, where the pH is consistently lower in the burned sampling station (*fig.* 2). A problem arose when trying to reconcile these findings with the reviewed existing literature, which claims a general trend of increased soil pH following a fire. Forest soils are acid in nature. When organic matter is burned, mineral substances are released as oxides and carbonates originating an alkaline reaction, which reduces acidity usually by 2 or 3 pH units (Viro, 1974). The differing results may depend on factors other than the effect of fire. The availability of mineral

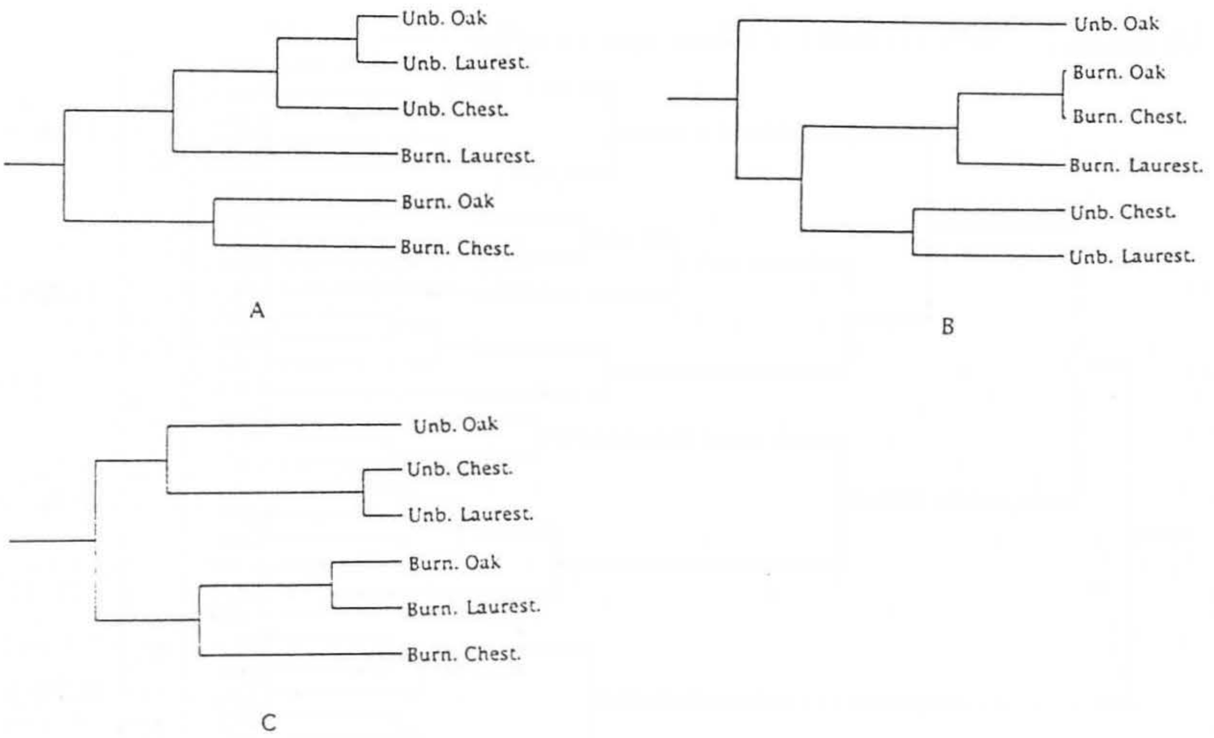

Figure 6. – Similarity analysis of the different sampling stations (Czekanowski'coefficient) in: A – Spring; B – Autumn; C – Winter.

nutrients along with soil chemical changes associated with burning can have a deep effect on bacterial populations. Their growth requirements may be fully satisfied in the burned soil of Mata da Margaraça, so that further study of a microbiological nature could explain these results.

The analysis of the studied populations puts in evidence a marked depression on collembolan densities observed in the summer period. The persistence of very dry soil conditions, associated with higher temperatures during the month of July, indicate that Collembola are intolerant to low moisture levels. This agrees with Neumann and Tolhurst's (1991) findings, who reported that the condition of soil dryness was associated with depressed collembolan activity irrespective of burning. A clear seasonal variation is also evident with maxima during Winter and Spring, suggesting that these are more favorable seasons for the collembola fauna.

The interpretation of the phenograms (*fig.* 3, 4, 5) and of Table 1 reveals that among the 44 species identified, *Bilobella aurantiaca, Stenaphorura quadrispina, Tetracanthella proxima* and *Lipothrix lubbocki* appeared exclusively in unburned sites, while *Brachystomella parvula* and *Proisotoma gisini* occurred only in burned ones. *Onychiurus insubrarius* presented an exclusive specificity for unburned laurestinus and *Folsomia quadrioculata* was the dominant species in the unburned oak station, corroborating the results obtained by Pozo *et al.* (1986). The great abundance of this species in this site in Autumn (*fig.* 6-B) must be responsible for the lower degree of similarity found between unburned oak and the other stations. The low similarity between unburned oak and the remaining unburned stations in Winter can, again, be explained by the high density of *F. quadrioculata* in this site (*fig.* 6-C). Some species like *Cryptopygus scapelliferus*, the best represented *taxon*, have a mixed distribution displaying equally high densities in burned and unburned sites. *Tullbergia* gr. *krausbaueri* and *Isotomiella minor*, however, revealed a marked preference for unburned sites, while *Ceratophysella engadinensis* and *Onychiurus gisini* occur more densely represented in the burned stations. The high density of this species and of *C. scapelliferus* in burned laurestinus, in Spring (*fig.* 6-A), must be responsible for the intermediate position of this site.

Although the fire intensity induced drastic disturbances in the soil conditions with disastrous results for the living organisms associated with it, the data obtained 2 years after the aggression suggests that the effect of burning on collembolan densities is smaller than had been anticipated. Burned sites still present higher densities associated to a slight decrease in the number of collembolan species. However, overall abundances in the burned and unburned stations reveal approximate values, which points to a restoration of prefire levels and is indicative that a quick regeneration is under way.

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